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The effects of adding salts to the soil on the amount of non-available water*

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In the experiments described in the following pages an attempt has been made to determine the effect upon the amount of non-available water, when varied amounts of sodium chloride or the salts of a full nutrient solution have been added to the soil. It has been found that with a soil of pure silica, containing about 0.03 per cent. of calcium, aluminum, and iron,† the amount of non-available water is not altered by the addition of either sodium chloride or the salts of a full nutrient solution. In the case of the sodium chloride series, at least, the water was used up by the plants faster than the salts, and as the point of non-available water was approached, the concentration of the soil water must have increased. In many cases the amount of sodium chloride was so great that the saturation point of the salt was passed long before the plant wilted. Adsorption, in some form or other, took place. We are concerned here then, not only with non-available water but also with the adsorption of salts from soil solutions.

Previous work on non-available water

In the late summer of 1859, Sachs[16] determined the retarding influence on transpiration, of various salts and soils. He then determined the amount of water retained by soils when tobacco

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*Contributions from the Department of Botany of the University of Missouri no. 18.

†See table of mechanical analysis of soil on page 279.

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plants wilted in a moist atmosphere. The soils used were a mixture of black beach humus and sand, a loam, and a pure sand (ground quartz). He found different amounts of non-available water in each of the soils; the beach humus having the greatest amount and the sand the least. He pointed out the importance of determining the amount of water available to plants in various soils, and showed that it bears no fixed relation to the amount of water which the dry soil will take up and hold (saturation capacity). He attributed the greater amount of non-available water in the humus soil to the greater adhesion between the water and the soil.

From the time of Sachs' paper, until Bogdanhoff[1] published his paper in 1893, but little attention was given to the subject of non-available water, though soil moisture received the attention of a great many investigators. In his paper, Bogdanhoff pointed out the errors introduced through chemical changes, when hygroscopic water is measured by determining the loss of weight in soils dried in an oven at 100° C. He found percentages of hygroscopic water, as measured by germinating seeds used as an indicator. Seeds were soaked until they had absorbed amounts of water nearly sufficient for germination. They were then mixed with the soil to be tested, using an excess of seeds, and stirring from time to time, so that all particles of the soil came in contact with the seeds. Seeds in this condition have strong absorptive powers and are able to take water from a relatively dry soil and begin growth. Varying percentages of water were mixed with a particular soil, and the lowest percentage which would permit growth determined.

In a sand containing 0.15 per cent. (by dry weight) of water, seeds germinated after 19 days; while in a sample containing 0.09 per cent., the seeds did not germinate, but lost water to the sand. He made measurements with samples of clay, but did not compare the clay with the sand, since the amount of germination could not be accurately determined, and the temperatures in the two sets of experiments were not held alike.

Heinrich,[9] in 1894, determined the amount of water contained in soils when plants begin to wilt, and also determined the hygroscopic water content. The hygroscopic water was determined by spreading the soils on a watch glass, and exposing them for one week to an atmosphere saturated with water vapor. The increase in weight was used as a measure of the hygroscopic water. His results show that, while the plant can live in a relatively dry soil, it can not use the hygroscopic water.

Edmond Gain[6] repeated the experiments of Sachs "with many plants in order to settle the following questions: (1) Is the power of resistance to drought of a given plant the same in different soils? This question must be answered in the affirmative. (2) Is the water content of the soil, at the time the plants wilt, the same for all stages of plant growth? No, it fluctuates in such a way as to produce a curve." He did not report the methods employed, nor give an analysis of the soils used.

A number of determinations of the amount of non-available water in various soils were made by King.[11] He concluded that one of the reasons why the clayey soils retained more water than the sands is because the small grains of the clay present more surface for retaining the water, the thickness of the film being the same in all cases. He gave a formula for computing the percentage of moisture in a soil which a given thickness of film will produce. By the use of this formula, a set of theoretical values was obtained, for the soils studied, which agree very closely with the percentages of non-available water found.

In 1902, Hedgcock[8] considered the relation of heat, light, and humidity to the amount of non-available water. His methods were such that he could not vary one factor while the others remained constant. The results as a whole would seem to show that any condition which lowers the vigor of the plant, raises the amount of non-available water. When he compared the various soils, he found that the amounts of non-available water retained by the soils increased in the following order: sand, loess, clay, loam, humus, saline soil. Judging from the sizes of the soil grains, the clay should have come after the saline, with the highest percentage. Hedgcock concluded that some factor other than the extent of soil surface is involved. The percentage of dissolved substances in the soil solution was the only condition noted that varied in the right direction. He, therefore, concluded that as the soil water diminishes, its concentration increases until finally it becomes so concentrated that plants are unable to absorb more He went so far as to formulate a law, that the percentage of non-available water in soils increases as the square root of the percentage of soluble salts.

Before using, all soils were sifted with a screen possessing a quarter-inch mesh. Other than this, the physical condition of the soil was not given closer attention than to list it as "loose, medium, or hard in density." A plant was considered, by him, wilted, when its youngest leaves wilt strongly. This would seem to be a very unreliable criterion, for many plants, at least. A geranium, for instance, will not only maintain its younger leaves, but will put out new shoots, after its roots have been killed. Many other plants behave in a similar manner.

Besides the above, a number of determinations of the amount of non-available water have been compiled, but aside from their local and immediate interest, they add nothing to our knowledge of non-available water.[10, 12, 17, 19]

ADSORPTION BY SOILS

The work done previous to 1908, on adsorption, has been recently reviewed by Patten and Waggaman,[14] so that a review of the literature need not here be given. The salient facts of interest in this connection are: Certain solids and liquids draw unto themselves and retain within their structures, or on their surfaces, other solids, liquids, or gases.* This is called *absorption.*

A special case of absorption, termed *adsorption,* is defined as the existence of a difference in concentration or density of a film adjacent to a bounding solid and the concentration or density of the mass of the liquid or gas which bathes the solid.†

Whether the relation between the adsorbing and adsorbed substances is physical or chemical, is not always clear; sometimes it appears to be one, sometimes the other. The difficulties involved in quantitative determination leaves us without a unit of adsorbing power, and with very few formulæ expressing the rate or conditions of adsorption.

When an adsorbent is brought into contact with a solution containing two or more solutes, these solutes may be adsorbed in different degrees, so that a more or less complete separation of the solutes is effected. Further separation may be reached by using two or more adsorbents, each with an adsorbing power specific for each solute. A number of investigators have used organic substances, such as charcoal, paper, and cotton to effect such separations. The separation is seldom complete, the adsorbed substance being distributed between the adsorbent and the solvent. No general laws governing the ratios of such distribution have been established.

**Loc. cit.* 10.

†*Loc. cit.* 11.

The solvent itself is often adsorbed, so that it increases very much in density at the surface of the adsorbent. This changes many of its physical characteristics; for instance, it is often able to hold the solute in solution at a concentration many times greater than normal saturation. This change in concentration is often accompanied by temperature changes which indicate enormous forces at work. The pressure of the water surface about a small solid (soil grain) has been estimated to have a magnitude of from 6000 to 25,000 atmospheres, or approximately 150,000 pounds per square inch.*

Now the soil grains present acres of surface to the soil solution, which, existing as it does, for the most part, in surface films is continuously within the field of adsorptive forces. We must expect, therefore, that adsorption will play important roles in the soil. Not only is the chemical content of the soil-solution affected, mineral nutrients stored up,[15] and toxins held harmless,[5] but the physical relations of the soil grains themselves are influenced.†

The field has been but little investigated, and most of the work has been done from the standpoint of physics and chemistry. Only a few investigators have taken up the problem from the standpoint of the plant, using it as an indicator. It would seem that this must be the ultimate point of attack, for the root hairs come into such a relation with the soil grains as to find a solution, the nature of which can be but little understood by any amount of study of the leachings from treated soils.

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*Whitney, Soils of the United States. U. S. Dept. Agric. Bur. Soils Bull. 55: 11. 1909.

†Cameron, F. K. and Gallagher, F. E. Moisture content and physical condition of soils. U. S. Dept. Agric. Bur. Soils Bull. 30: —. 1908.

Not only this, but the root hairs, with their cellulose walls, are absorbents, and undoubtedly engage in selective absorption with the soil grains, so that there are ratios of distribution, between the soil grain, the film of soil water, and the cell wall.[18] Physiological processes in the plant will continually disturb the equilibrium of distribution. A series of changes must then follow before the equilibrium is again established. It was with the hope of getting some data regarding the nature of this equilibrium that the experiments described below were undertaken.

EXPERIMENTS AND RESULTS ON THE INFLUENCE OF SALTS ON NON-AVAILABLE WATER

From a number of plants used in preliminary experiments, wheat was selected as most suitable. Its superiority lies in the smallness of its seed, so that it early becomes dependent upon the soil solution, and in the tenderness of its leaves, which makes it very sensitive to a deficient water supply. Some of the plants were grown in paraffined baskets; others in flower pots dipped in hot paraffin. Both the baskets and the pots seemed to give good results, but the pots were easier to prepare. Later, when it was found, by weighing the empty pots, that they had slowly absorbed water, their use was discontinued. Glass tumblers were then tried, and were found very satisfactory. The roots spread evenly through the soil, showing no tendency to mat about the inner surface of the glass.

In the first experiments, the plants were grown in river-washed sand, but in the experiments from which the data given below were taken, the plants were grown in clean crushed quartz, obtained from a supply house. The chemical analysis of the quartz, furnished by the supply house, is as follows:

	Per cent.
Absolute silica	99.97
Iron, aluminum, calcium	.03
	100.00

The fresh samples were very white, but, after standing, a yellow tint, just perceptible when old samples were compared with new, was noted. This was probably due to thin films of iron oxide which formed on the surface of the grains.[4] The physical analysis is given in the table below:

	Size.	Per cent.
Gravel	2 mm. +	0.00
Fine gravel	1–2 mm.	0.00
Coarse sand	1–.05 mm.	3.60
Medium sand	0.5–0.25 mm.	20.51
Fine sand	0.25–0.1 mm.	72.72
Very fine sand	0.1–0.05 mm.	2.69
Total		99.52

A full nutrient solution was made up as follows:

		Gm.
Calcium nitrate $Ca(NO_3)_2+4H_2O$	15.83 gm. $=Ca(NO_3)_2$	11
Potassium nitrate	KNO_3	3
Magnesium sulphate $MgSO_4+7H_2O$	6.85 gm $=MgSO_4$	3
Potassium phosphate	KH_2PO_4	3
Total		20

Water to make 10,000 c.c. of solution.

This solution gives a concentration of salts equal to 0.2 per cent. The same stock solution was used throughout the entire series of experiments. To portions of this full nutrient solution, quantities of sodium chloride were added so that series of concentrations (salts of full nutrient solution plus sodium chloride) of the following order were made: 0.2 per cent. (control), 0.225 per cent., 0.25 per cent., 0.3 per cent., 0.4 per cent., 0.5 per cent., 0.65 per cent., and 0.8 per cent. In another series, the percentage of the total salts in the nutrient solution was increased, so that, without the use of the sodium chloride, the following series of concentrations were made: 0.2 per cent. (control), 0.25 per cent., 0.4 per cent., 0.6 per cent., and 0.8 per cent.

The solutions were made upon the percentage basis, because it is impracticable, when dealing with selective adsorption and water films, to make up solutions in the ratios of their osmotic strengths. Moreover, the questions in mind can be answered equally as well with simple percentage solutions.

Sodium chloride seemed a suitable salt to use since it does not readily penetrate plant protoplasm and since it ordinarily contains no water of crystallization. Further, Briggs[3] has shown that sodium chloride is but slightly adsorbed by quartz. The series without the sodium chloride served as a check on the purely toxic effects of the sodium chloride.

The quartz was wetted with the solution, so that it contained a 20 per cent. (20 grams of solution, plus 100 grams dry quartz) soil moisture. The air-dry quartz was weighed out, to the 1/10 gram, in portions sufficient nearly to fill the tumblers. It was then spread over the bottom of a tray. The solution was added to the quartz in such a manner as to prevent, as far as possible, any uneven adsorption of the salts by the soil grains first wetted. After quickly mixing, the soil was dropped into the tumblers. When this quartz is carrying a 20 per cent. soil solution, it contains more than its optimum amount of water.* However, it was dropped into the tumblers in such a manner as to include air enough to supply the plants as long as it was necessary to grow them. By pounding the tumblers up and down on the table a few times, the inclosed air was worked out of the upper centimeter of the soil, which puddled, leaving a thin layer of free water on the upper surface. This also worked the air entrapped below the surface into quite large bubbles, the largest being about 5 mm. in diameter. The physical condition of the soil, thus obtained, appeared to be uniform throughout both series.

Melted paraffin was poured over the surface of the quartz in each tumbler, five small holes were made through the cover thus formed, and then the wheat seeds, which had germinated in Zurich germinators until the radicles were from five to ten millimeters long, were dropped through the holes into the water layer on the surface of the soil. Five tumblers of each concentration were set up.

The plants were grown in the glass house on a table in the center of the room, where they were under similar conditions, until they were ready to be wilted down. There was a marked difference, among the several concentrations, in the rate and amount of growth. With the exception of the 0.225 per cent. set, in which there was a stimulation, due undoubtedly to toxic effects, there was a regular decrease in both the rate and the amount of growth from the control set to that of the highest concentration. Plants that grew fastest used up their water first and were the first to wilt.

When the water was nearly used up, as was determined by repeated weighings of the tumblers, the plants were put into a culture case, where a relative humidity of approximately 10 per cent. was maintained. The culture case, as described in another paper,[2] contained a thermograph, a hygrograph, and an electric fan. The humidity was controlled by regulating the volume of a stream of air, dried by passing through sulphuric acid, and forced into the case by means of an air pump.

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*It was necessary to use an excess of water so as to have enough to allow the plants to put on sufficient growth before wilting.

Wilting the plants in a relatively dry atmosphere, practically solved the problem of knowing when to consider them wilted. These plants did not show temporary partial recoveries from the drouth effects, as others did which were grown under fluctuating conditions of humidity. Moreover, the leaves dried out immediately after death, so that it was possible to see the progress of death over the various members of the plant and to have each culture stopped at the same stage of wilting—a very important detail in non-available water determinations. A study to determine the effects of relative humidity on non-available water is now in progress, but the results of this study are not necessary for the present paper, since in the experiments here reported, all of the plants were under like conditions of humidity.

As soon as the plants had wilted, the tumblers were removed from the case, and the amount of non-available water determined in the following manner: The quartz was passed through a screen, having 20 meshes to the inch, which removed all the roots. A sample of about 80 grams of the quartz was put into an aluminum dish and weighed on a chemical balance.* The sample was then dried at 110° C. for one week. It was found that this amount of desiccation was sufficient to insure constant weight.

From the loss of weight in drying, the percentage of non-available water was determined, then the total water remaining in the soil was calculated, also the concentration which this water would have had, had it existed as free water,—assuming that the plants had used up none of the salts and neglecting any water of crystallization. The results of the determinations are given in the following table:†

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*These operations were carried on in the laboratory and probably permitted some experimental error to enter. However, as little time as possible was consumed before the weighings were made. The sifting was done in a small closed vessel.

†The numbers refer to the amount of salts added; thus 25a means that a 0.25 per cent. solution of sodium chloride and full nutrient salts were added to the quartz. Sets from *a* to *e* contain sodium chloride, sets from *l* to *p* contain no sodium chloride.

Number.	Amount of desiccation.	Per cent. of non-available water.†	Total concentration of all salts in per cent.	Concentration of sodium chloride in per cent.
2a	—	—	—	—
2b	dry	.03	125.	—
2c	wilted	.14	29.4	—
2d	dry	.05	87.	—
2e	dry	.04	94.	—
225a	wilted	.16	28.1	3.1
225b	wilted	.12	37.	4.1
225c	wilted	.07	62.5	7.
225d	dry	.04	115.7	12.9
225e	wilted	.13	34.8	3.9
25a	—	—	—	—
25b	wilted	.07	69.5	13.9
25c	wilted	.14	35.5	7.1
25d	dry	.07	74.8	15.
25e	wilted	.17	30.	6.
3a	dry	.03	192.5	64.2
3b	dry (partly)	.12	51.3	17.
3c	dry	.06	98.2	32.7
3d	wilted	.19	31.	10.3
3e	dry	.05	129.5	43.
4a	—	.04	206.	103.
4b	wilted	.11	69.1	35.
4c	—	.05	162.	81.
4d	—	.04	210.	105.
4e	dry	.04	231.	115.
5a	dry	.04	252.	151.
5b	dry	.03	315.	189.
5c	dry	.03	352.	212.
5d	green	.19	53.	32.
5e	dry	.03	312.	187.
65a	—	—	—	—
65b	—	.10	132.	91.5
65c	—	.05	254.	175.5
65d	—	—	—	—
65e	—	—	—	—
8a	green	.376	43.	31.
8b	dry	.06	275.	207.
8c	dry (partly)	.06	254.	190.
8d	green	.31	52.3	39.
8e	dry	.04	388.	292.
2l	dry	.18	27.2	—
2m	wilted	.25	16.	—
2n	dry	.06	55.	—
2o	wilted	—	—	—
2p	dry (partly)	.14	29.	—
25l	dry	.13	37.5	—
25m	dry (partly)	.18	27.5	—

†Recorded to nearest 1/100 per cent. only.

Number.	Amount of desiccation.	Per cent. of non-available water.†	Total concentration of all salts in per cent.	Concentration of sodium chloride in per cent.
25n	green	.34	15.	
25o	dry	.09	54.	
25p	dry	.05	98.	
4l	dry	.06	125.	
4m	dry (partly)	.15	52.5	
4n	dry	.09	90.	
4o	wilted	.25	32.	
4p	dry (partly)	.1	79.5	
6l	dry	.14	89.	
6m	dry	.09	128.5	
6n	dry	.09	141.	
6o	dry	.11	105.	
6p	dry	.09	140.	

The non-available water relations are more clearly represented by the graphs 1, 2, and 3. Graphs 1 and 2 are details of the sodium chloride and the full nutrient series, respectively. Graph 3 is a combination of 1 and 2, enlarging the scale of the ordinate 10 times, and indicating the determinations only in part. Referring to graphs 1 and 2, it will be seen that, with but a single exception, the amount of non-available water in the soil varies with the amount of desiccation which the plant has experienced. Cultures in which the plants are just beginning to wilt have the most; and those in which plants have dried have the least. Also, even in the culture containing the highest percentage of non-available water, the soil solution represents a concentration of 43 per cent. That the plant actually lived in these high concentrations is shown by the fact that in some cases the plants were still green when the sample was taken. Further, cultures in which plants are completely wilted, *i. e.*, plants just beginning to dry, have about 0.1 per cent. of non-available water, regardless of the amount of salts in the culture. Drawn across graph number 3, is a line representing the amount of water which the several sets had when the concentration of the soil water had reached 6 per cent. It is to be noted here that the plants in the cultures were not exposed to free water containing 6 per cent. of salt. The 6 per cent. curve lies so low that all the water in the quartz was in the form of *film water*, before this concentration was reached. No data have been found regarding isotonic values in film-water, a

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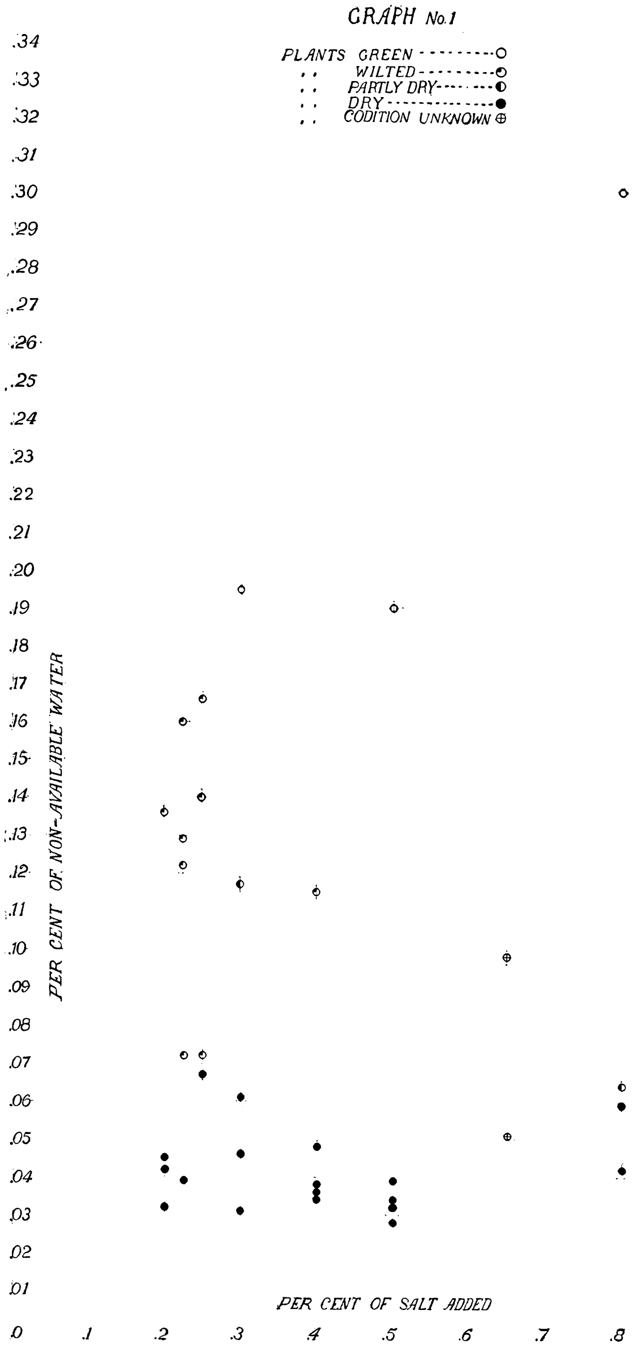
†Recorded to nearest 1/100 per cent. only.


GRAPH No. 1
PLANTS GREEN ---------○
" WILTED ---------◐
" PARTLY DRY --------◐
" DRY ------------●
" CODITION UNKNOWN ⊕
PER CENT OF NON-AVAILABLE WATER
PER CENT OF SALT ADDED
.34
.33
.32
.31
.30
.29
.28
.27
.26
.25
.24
.23
.22
.21
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.19
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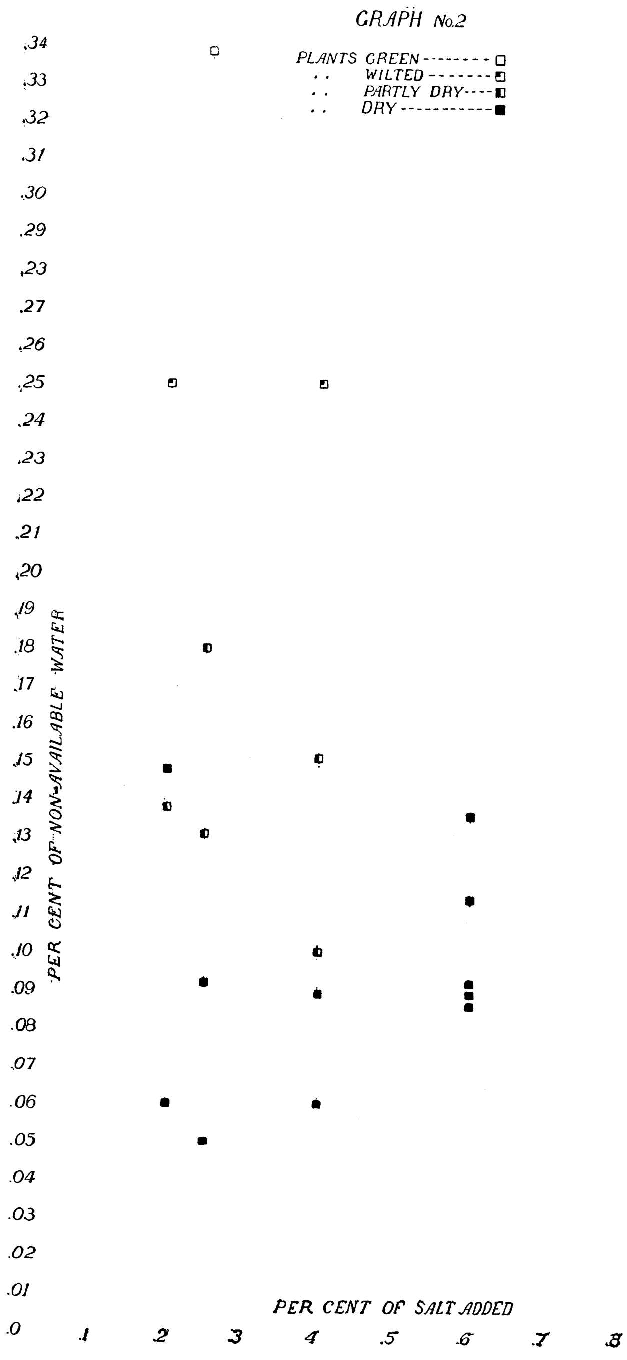
GRAPH No.2
PLANTS GREEN -------- □
.. WILTED -------- ◩
.. PARTLY DRY ---- ◧
.. DRY ----------- ■
PER CENT OF NON-AVAILABLE WATER
PER CENT OF SALT ADDED
.34
.33
.32
.31
.30
.29
.23
.27
.26
.25
.24
.23
.22
.21
.20
.19
.18
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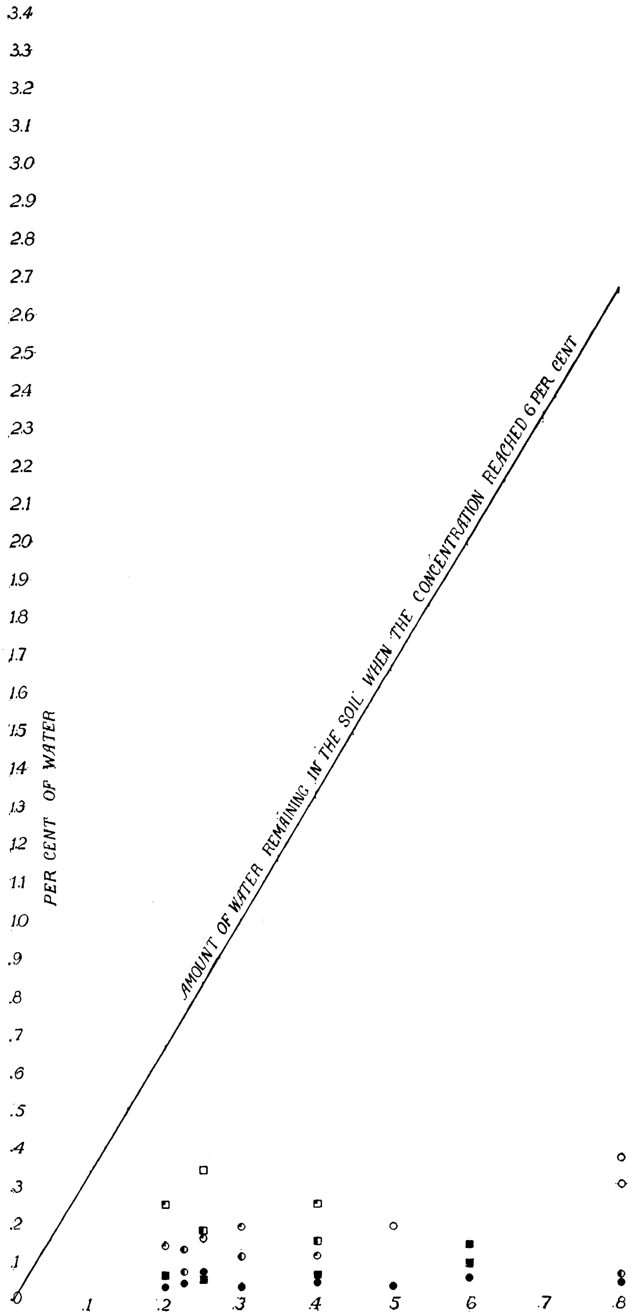
GRAPH No. 3


3.4
3.3
3.2
3.1
3.0
2.9
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2.4
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2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
PER CENT OF WATER
AMOUNT OF WATER REMAINING IN THE SOIL WHEN THE CONCENTRATION REACHED 6 PER CENT
.1
.2
.3
.4
.5
.6
.7
.8

form of water which land plants use for a large part of their lives. The uniformity in the above results testifies to the smallness of experimental errors in sampling, weighing, et cetera.

The amount of non-available water was not determined in the 0.8 per cent. set of the full nutrient series, as these plants were used for a study of some of the physiological conditions of the plants at wilting time. One point, of vital interest here, is the amount of adjustment to concentrated solutions which the plants may have made.

The cell sap of the roots of normal wheat plants is isotonic with solutions which contain a concentration of sodium chloride lying between 3 per cent. and 6 per cent. A plant was removed from the tumbler of the 0.8 per cent. set, after all the plants in the tumbler, save this one, had wilted. The plant was removed by sluicing with a small stream of water, a number of uninjured root tips thus being obtained. The root tips were placed on a slide, under the microscope, and the concentration of the cell sap in cells of the tip was determined by the plasmolytic method. There was no plasmolysis with a 3 per cent. sodium chloride solution. A 6 per cent. plasmolyzed. Turgor was restored by tap water, the cells appearing normal in every way. The plants, therefore, did not adjust themselves to the various soil solutions by materially increasing the concentration of their cell sap.

There were, however, visible modifications in the plants due to the influence of the salts added. Increase in the amount of bloom, as mentioned by Harter,[7] was not observed, but there was a uniform decrease in the rate of transpiration. The leaves of the plants grown in the higher concentrations felt harsh to the fingers. A microscopical study of the leaves was not made, but possibly this harshness was due to some modification in the structure of the cell walls, as found by Harter. As mentioned above, there was a correlation between the size of the plants and the amount of salts added, the plants in the higher concentrations being much smaller. This is of special interest, for not only was the area of leaf surface reduced, in plants grown in the higher concentrations, but their root systems were proportionately reduced. In the 0.8 per cent. set the roots developed only in the upper one third of the tumblers. It follows, therefore, that the roots of the plants in the higher concentrations came into contact with a much smaller proportion of the total surface presented by the soil grains. Yet, the percentage of non-available water, remaining in these tumblers, was no greater than that found in the lower sets, which indicates a water transfer from the more remote parts of the tumbler to the root systems of the plants. At first, when the soil was very moist, this transfer might have been made by the movement of the liquid water over the soil surfaces, but as these films became thinner, the movement would become slower, and at last, when the films became discontinuous, the movement would stop altogether. The only method of transfer, then, would have been in the form of vapor, and before the soil moisture could have been reduced to as low a percentage as was found in these experiments, this kind of transfer evidently must have taken place.

But little is known concerning the vapor pressure of soil moisture.[13] It may be expected, however, to vary with the shape of the film surfaces, with the surface tension, with the thickness of the film, and with the concentration of the solutes present. If, by a change in any of these conditions, the vapor pressure of the soil moisture about the roots is lowered below that of the surrounding soil, there will be a movement of water vapor toward the plant roots, and then a condensation. More than this, the water which permeates the plant roots together with their root hairs has a vapor tension and thus the roots must either give off water in the form of vapor or take it in, as they are in an atmosphere with a vapor tension either lower or higher than that of their own moisture. The common practice of growing plants in a damp chamber is evidence of this.

In the above-described experiments, the air cavities, in the quartz, were lined with projecting root hairs, which were often so numerous as to give the cavity the appearance of having walls covered with a delicate fur coat.

The writer has undertaken some further experiments in regard to the relation of plants to vapor tension; while no numerical results have been obtained, the preliminary experiments show that plant roots are very sensitive to variations in vapor pressure.

In regard to the influence of the concentration of soil moisture upon vapor tension and water transfer, the following experiment has been completed. Five tall glass tumblers were selected, and 100 grams of dry river sand placed in the bottom of each tumbler. The sand in tumblers 1 and 2 was moistened with 10 grams of distilled water. To the sand in tumbler number 3, 10 grams of a 5 per cent. solution of sodium chloride were added. The sand in tumbler 4 was wetted with a 15 per cent. solution, and the sand in number 5 with 10 grams of a 20 per cent. solution of the same salt. A cloth diaphragm was then fixed in each tumbler, 3 centimeters above the sand, thus leaving a free air-space between it and the sand. One hundred grams of sand were placed upon the cloth diaphragms of each of the tumblers. This sand, in all of the tumblers except tumbler number 2, was moistened with 10 grams of distilled water. Tumbler number 2 had 10 grams of a 10 per cent. salt solution added to the sand above the diaphragm. After being sealed by tying sheet rubber over the top, the tumblers were then set in the basement, where there was but very slight variation in temperature (at least not more than occurs in field soils). After 10 days they were opened, and the amounts of water in the two layers of sand determined. As shown in the table, there

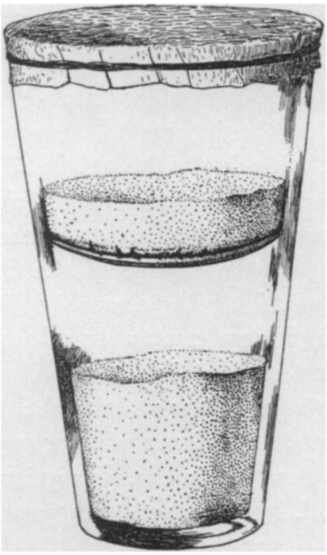

FIGURE 1. Apparatus for showing the influence of salt on vapor transfer in soils. Description in text.

was, in every case, a transfer of water to the soil containing the salt solutions. Moreover, the transfer was made, by water in the form of vapor, across the air space. The water moved from the region of higher vapor pressure to the region of lower vapor pressure, and then condensed.

No.	Solution added below.	Solution added above.	Transfer of water in grams.	Direction of transfer.
1	Dis. H_2O	Dis. H_2O	1.35	down
2	"	10 per cent. NaCl	2.17	up
3	5 per cent. NaCl	Dis. H_2O	2.40	down
4	10 per cent. "	"	3.85	"
5	20 per cent. "	"	5.95	"

It will be noted that, in tumbler number 1, with distilled water both above and below the diaphragm, there was a transfer downward. This was probably due to the weight of the column of vapor in the glass. This difference was further shown by the difference in results from tumblers 2 and 4, where the condition in tumbler number 2 was the inverse of the condition in tumbler number 4, the salt solution being above the diaphragm in number 2, and below the diaphragm in number 4. In tumbler number 2, the water was transferred against the pull of gravity, while in tumbler number 4 the transfer was with the pull of gravity. As expected, the amount of transfer in number 4 was greater than that in number 2. It is possible that water condensed in drops on the sides of the glass and, in some cases, ran down. This error, however, is not very large, and could not explain the results of number 2, nor the regular curve which all the results produce when plotted. Furthermore, there was no visible evidence of such a transfer. The amount of transfer in number 3, which had a concentration of soil moisture of the same magnitude as that of my cultures some time before the plants wilted, would have been sufficient to have raised the percentage of soil moisture to within the limits of available water.

Conclusions

1. In these experiments, it has been shown that the amount of non-available water is not influenced by adding to pure quartz the quantities mentioned above of either sodium chloride or the salts of a full nutrient solution.

2. Practically all plants of economic value are land plants, and hence, for both their water and food supply, are dependent on water

films. Therefore, it is important that we understand the conditions of equilibrium between the plant and this form of water.

3. It is apparent that the isotonic values determined for substances dissolved in free water do not necessarily hold for film-water. We cannot thoroughly understand the acquisition of water and food by land plants, or the results from fertilizer experiments until some of these values are known. Further, the conditions of equilibrium *in film water* must be determined for both toxic and "balanced" solutions, before we have reached a logical stopping place for these lines of research.

4. The investigations should be carried out with carefully controlled experiments, in which the number of unknown factors is reduced to a minimum. Fundamental principles will scarcely be demonstrated by experiments on soils chosen at random in the field. Such soils contain too many unknown factors. Experience shows that experiments from soils from the same locality may not yield comparable results. The soil used should be of simple composition, and its content known. We must have a number of simple standardized soils, of which samples can be duplicated. I have used a soil with comparatively few unknown factors, and one that is to be had in practically unlimited amounts. These experiments can be duplicated.

5. Much of our knowledge of the relation of plants to the soil must be obtained by indirect methods. A great deal of it must be worked out in the laboratory of the physical chemist. But all such results should be checked up by experiments with the plant itself, for the problem of the relation of plants to the soil is primarily a problem in botany, both in its inception and final solution.

The greater part of this work has been done under the direction of Professor C. Stuart Gager, whose suggestions and encouragement have been invaluable in its prosecution.

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